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Equatorial Ionospheric Irregularities study from ROCSAT data

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14. ABSTRACT
Ionospheric irregularity/scintillation occurrences can be caused by external driving elements, such as the global fast penetration electric field during a storm period. Under such conditions, the longitudinal/temporal occurrences of irregularities/scintillation will depend on the appearance and disappearance of the global fast penetration electric field. The AFRL-NCU SCINDA Pingtung station observed such an example during the 2015 St. Patricks Day superstorm period. Comparing the occurrences and non-occurrences of irregularities/scintillation in the Indian and Taiwan sector, it was concluded that the longitudinal/local-time dependence of irregularity/scintillation occurrences at the two different longitudinal sectors was due to the southward turning of interplanetary magnetic field that caused the appearances and disappearances of the global fast penetration electric field.

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"Study of Equatorial Ionospheric Irregularities for the Assessment of Impacts on communication/Navigation System (VIII)

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Abstract

Ionospheric irregularity/scintillation occurrences can be caused by external driving element such as the global fast penetration electric field during a storm period. Under such condition, the longitudinal/temporal occurrences of irregularities/scintillation will depend on the appearance and disappearance of global fast penetration electric field. The AFRL-NCU SCINDA Pingtung station happened to observe such an example during the 2015 St. Patrick's Day superstorm period. Comparing the occurrences and non-occurrences of irregularities/scintillation in the Indian and Taiwan sector, we have concluded that the longitudinal/local-time dependence of irregularity/scintillation occurrences at the two different longitudinal sectors is due to the southward turning of interplanetary magnetic field that causes the appearances and disappearances of global fast penetration electric field.

We have also obtain a global/seasonal irregularity/scintillation distributions using the GPS-FORMOSAT3/COSMIC L1 beacon data during 2006-2012 low solar activity period, and the in-situ density measurement from ROCSAT-1 during

1999-2004 high solar activity period. Although the two separate data sets are used to complete two different papers. The irregularity/scintillation occurrence characteristics and global/seasonal distribution for low and high solar activity periods will further add our understanding of ionospheric irregularity occurrence mechanism.

Experiment, Result, and Discussion:

1. **Study of scintillation events with data taken at AFRL/NCU-SCINDA Pingtung station.**

(a) Suppression of ionospheric scintillation during St. Patrick's Day geomagnetic super storm as observed over the anomaly crest region station, Pingtung, Taiwan: A case study.

AFRL/NCU-SCINDA Pingtung station observed a scintillation suppression event during the St. Patrick's Day geomagnetic storm period on March 17 to 19, 2015. There were scintillations observed from March 11 to 16, six days in a row by the Pingtung SCINDA station, but scintillations disappeared on the storm day and thereafter. However, density irregularities (and hence scintillation were observed at the Indian sector, some 4,000 km west of Pingtung station (Taiwan sector). The cause of scintillation suppression on the storm day at Taiwan sector can be explained from the north-south turning of interplanetary magnetic field that changes the polarity of prompt penetration electric field at different longitudinal location (Indian sector vs. Taiwan sector) at different local time.

Figure 1 shows data taken by ESA SWARM satellite on March 16 and 17 indicating density irregularity was observed on March 17 but not on March 16 at Indian sector. While Taiwan sector shows no irregularity occurrences on both days. Figure 2 shows data taken at Pingtung station from March 11 to 19. Scintillations were observed from March 11 to 16, but no scintillations were observed from the storm day (March 17) to 19. Figure 3 shows the interplanetary magnetic field (IMF) and the storm time SYM-H variations during this period. In the figure, we notice that the interplanetary magnetic field and the storm-time Dst variations that are closely related to the existence and disappearance of prompt electric penetration change at difference longitude sector at different local time to cause the appearance and disappearance of irregularities (scintillations) at different longitude sector (Indian sector vs. Taiwan sector) at different local time.

The result of the study was presented at 2016 AGU Fall meeting held at San Francisco, Dec 12 to 16, 2016 [Su et al., 2016]. A complete paper has been accepted for publication in the journal of Advances in Space Research [Nayak, et al., 2016].

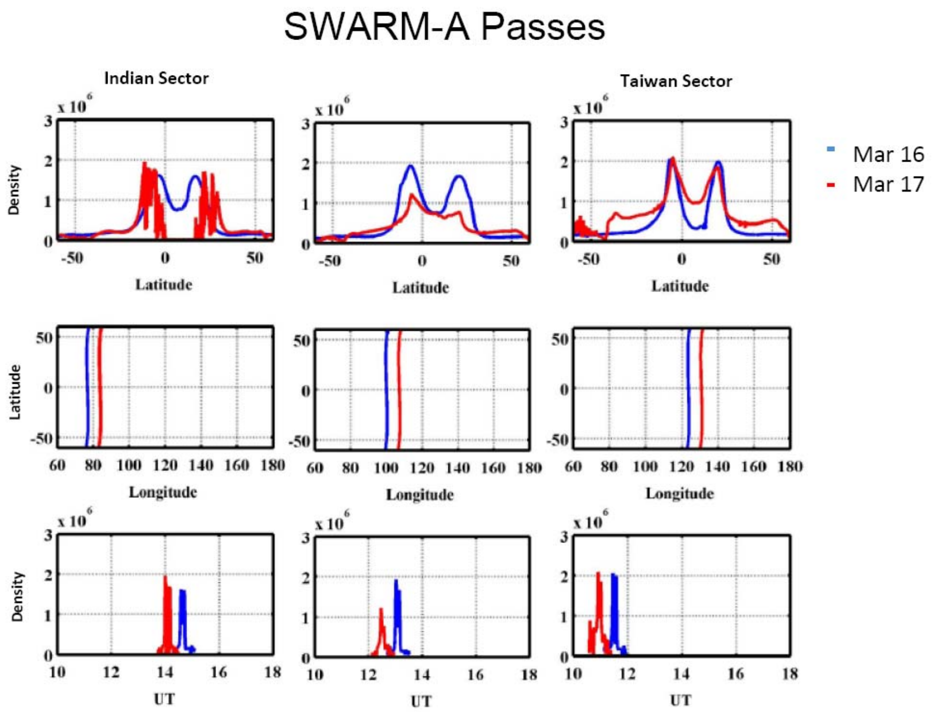

Fig. 1. Density observations from the polar orbiting satellite SWARM-A on March 16 and 17, 2015

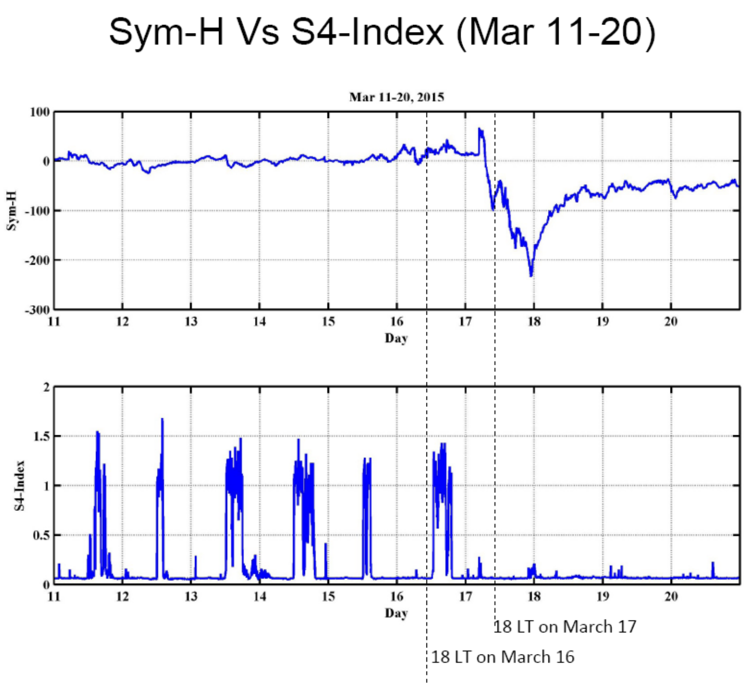

Fig. 2. Ground SYM-H variation versus scintillation (S4) observed by Pingtung station.

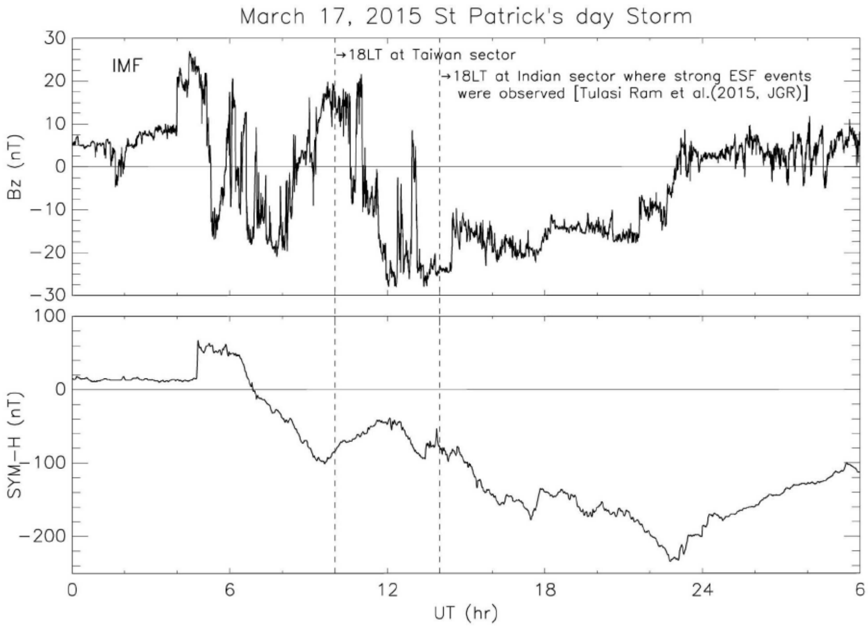

Fig. 3. Variation of IMF on the storm day in comparison with the SYM-H variation.

(b) Seismo-traveling ionospheric disturbance (STID) observed in the radio beacon data for the March 2, 2015 Indonesia Earthquake.

Signals in a time-series are not always stationary or linear. The best way to analyze such data is, to our best understanding, using the so-called Hilbert-Huang transform (HHT). The HHT method is a self-adoptive time-series analysis that decomposes the data into many components (IMF, intrinsic mode function) each has a perfect Hilbert transform and exhibits distinctive oscillation frequencies. Using the HHT method to analyze the radio beacon data, we can find some hidden oscillations at some particular frequency in the signals that is not related to the density irregularities. The following shows such an example.

Figure 4 shows the radio beacon signals taken by the two channels on March 2, 2015. Before the onset of scintillation at 14.8 UT, there seems some undulation existed in the beacon signal. The HHT analysis (Figure 5) reveals that definitive oscillation exists at C13 and C14 components of both channels. Interestingly, the distinctive oscillations in these two components are that there is no time-lag between the two signals in comparison to the scintillation data that indicates lag as shown in Figure 6. The time lag in the scintillation is caused by the eastward drifting irregularities with the background plasma. Therefore, the oscillation noticed in the

period before 14.8 UT could be caused by some disturbances traveling in the north-south direction. In this case, it could be caused by a large earthquake (M=7) on March 2, 2015 in Indonesia. This is the so-called seismo-traveling ionospheric disturbances (STIDs) from a large Earthquake. Preliminary result was presented at 2017 AGU Fall meeting at San Francisco, Dec 12-16, 2016 [Nayak et al., 2016].

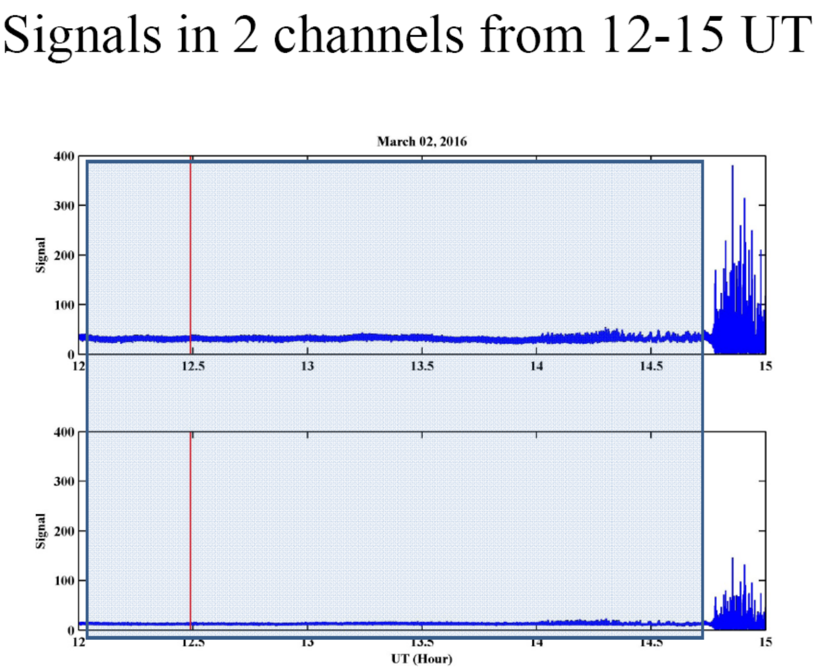

Fig. 4. Apparent undulations noted in the data before the onset of scintillation in both channels.

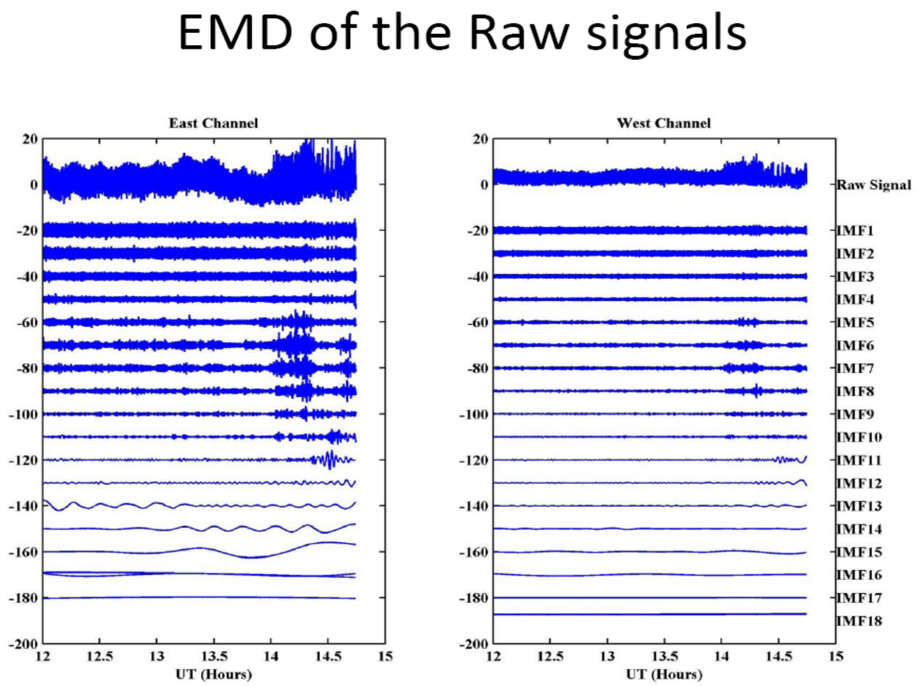

Fig. 5. HHT decomposition of the data indicates some oscillation existed in IMF components 13 and 14.

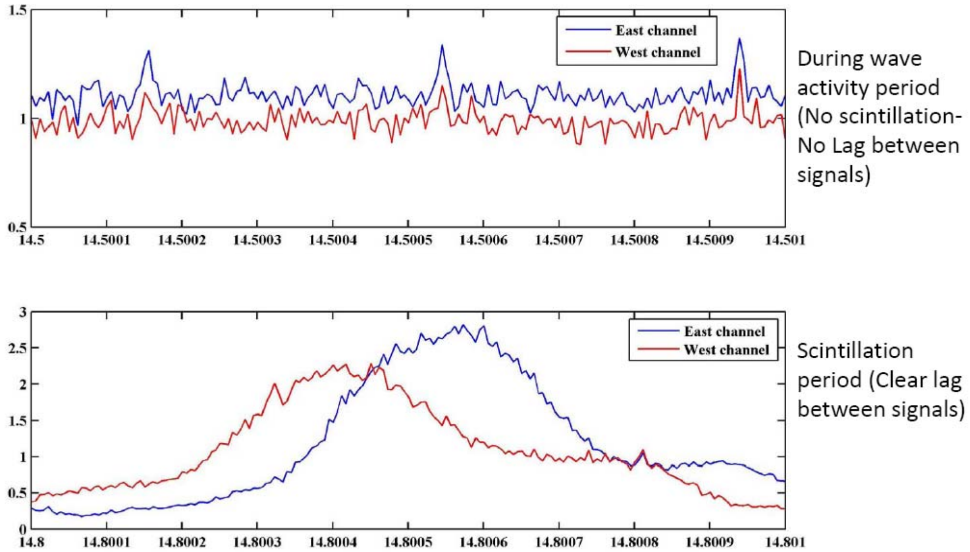

Fig. 6. Over-lap of HHT components from two channels reveals that there is no-lag between the signals for data before the onset of scintillation at 14.8 UT, while lag was noticed in the scintillation signals.

2. **Study of global scintillation distribution with FORMOSAT-3/COSMIC radio occultation (RO) data.**

Study of FORMOSAT-3/COSMIC constellation satellites' radio occultation (RO) observations was not included in our original proposal for the study period 2014-2017. However, we found that signals (GPS L1 band) received by these satellites during occultation with GPS satellites can be used to derive the global scintillation distributions during solar minimum years from 2006 to 2012. Figure 7 shows how RO signals are obtained by F3/COSMIC satellites, and Figure 8 shows how scintillation signals look like. The global scintillation distribution for 2006 is shown in Figure 9. The equatorial distributions of scintillation pattern are well known and have been reported in many published papers. However, the midlatitude scintillation patterns in the European and Japan sea sectors, as well as in the polar region are not well understood. These scintillation distributions will be studied in 2017-2018 years. The result has been written into a paper "Global morphology of ionospheric F-layer scintillations using FS3/COSMIC GPS radio occultation data" and has been accepted for publication in Journal of GPS Solution [Tsai et al., 2016].

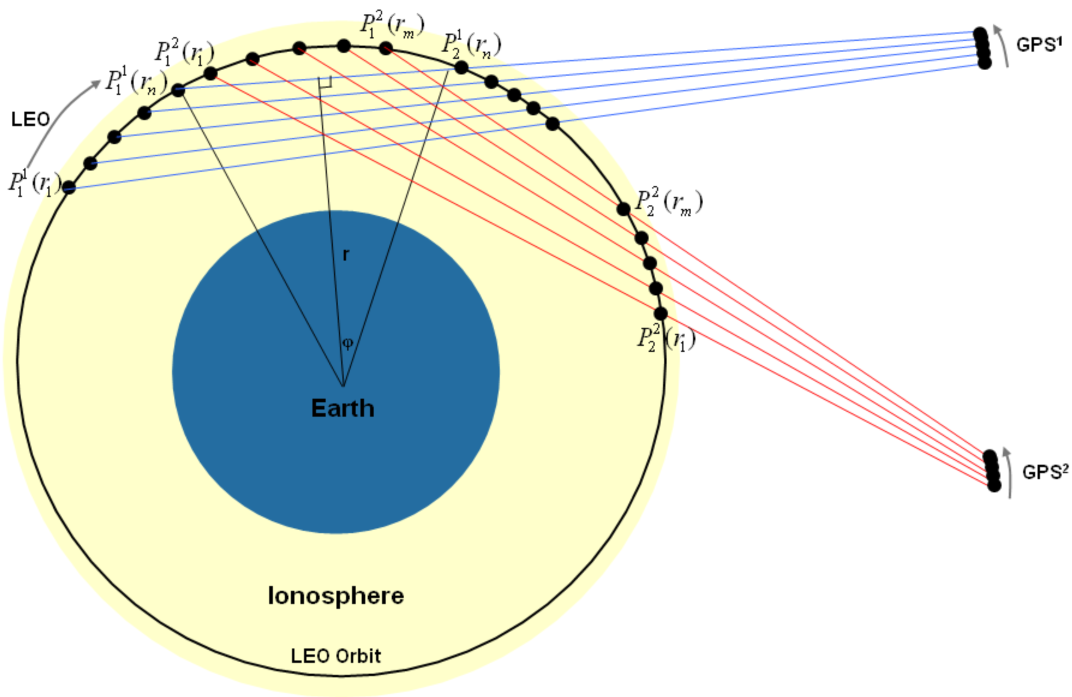

Fig. 7. Illustration of the GPS-LEO occultation problem geometry for ionosphere observations under the assumptions of straight-line ray propagation and co-planed LEO and GPS orbits. $P_1^{i}(r_k)$ is the kth occulting LEO position from the ith GPS satellite within a RO observation, and $P_2^{i}(r_k)$ is its corresponding calibration position, where r_k is the tangent point's radial distance along the GPS-LEO line-of-sight. Note that this illustration is not to scale.

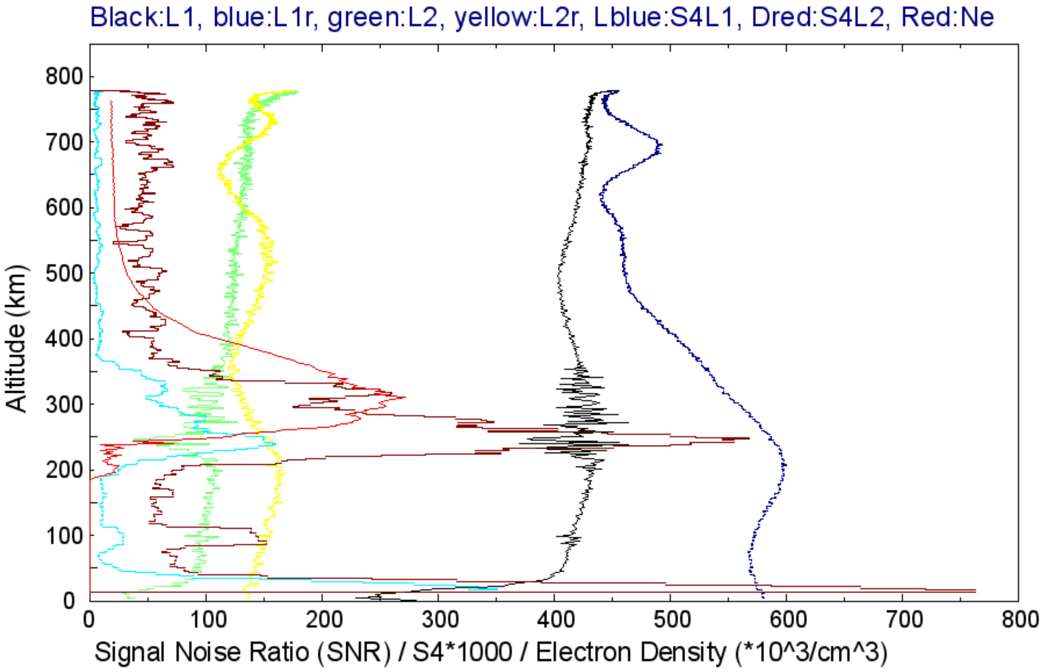

Fig. 8. Example of FS3/COSMIC RO observation with amplitude scintillation, which shows the limb-viewing SNR amplitude profiles at the occulting side in black and green for L1 and L2 bands respectively and the resulting *S4* profiles in cyan and dark red. The retrieved electron density profile is shown in red. It also shows the limb-viewing SNR amplitude profiles at the auxiliary side in blue and yellow for L1 and L2 bands respectively.

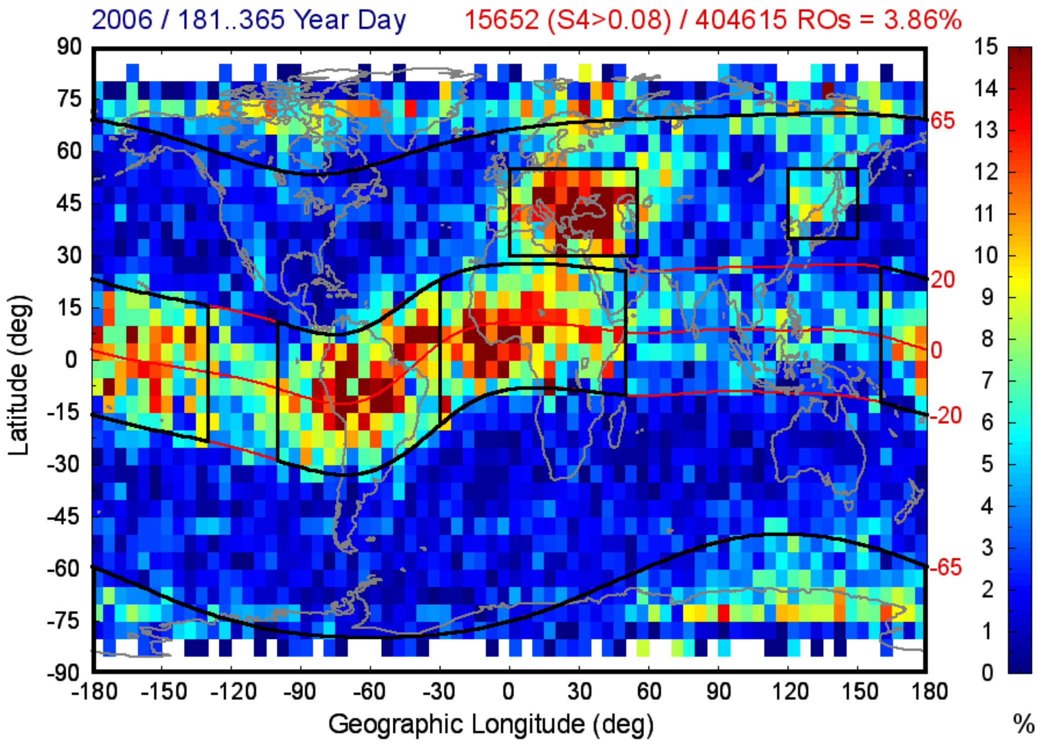

Fig. 9. The global occurrence distribution of L1-band large-*S4* (>0.08) F-layer scintillation from the middle to end of 2006 as labeled at the upper left of this figure. As shown at the upper right, there are more than fifteen thousand larger-*S4* observations from four hundred thousand FS3/COSMIC RO observations, i.e. 3.86 percent on average. Coded color represents the large-*S4* occurrence rate from zero to fifteen percent within every 5° by 5° in the geographic bin. Seven typical areas enclosed by black lines are chosen and identified based on the occurrence statistics.

3. **Revised the paper "Post-midnight Equatorial Irregularity Distributions and Vertical Drift Velocity Variations During Solstices," and submitted to a special issue of Advances in Space Research for publication [Su et al., 2017].**

The paper changes the original title of "On Seasonal/longitudinal Distributions of Post-Midnight Quiettime Equatorial Ionospheric Irregularities" presented at the 14th International Ionospheric Effects Symposium, Alexandria, VA, May 12-14, 2015 and submitted to a special issue of Advances in Space Research (ASR) for publication on March 30, 2017. The revised paper now presents a comprehensive picture of how the post-midnight vertical drift velocity and density play the key roles in determining the global longitudinal distributions of irregularity occurrences during solstices. Subtle differences in the irregularity occurrence distributions

between the published results taken during low solar activity years and the current result taken during high solar activity years can be explained by the effect of transequatorial wind resulting in asymmetrical hemispheric ionospheric density distributions.

Highlights of the revised paper are recapitulated in the following. Figure 10 shows the comparisons of the post-midnight irregularity occurrences and the background vertical drift velocity and density variations. Visual inspection of Figure 10 can convince us that longitudinal distributions of post-midnight irregularity occurrences are mostly collocated with the longitudes of high mean vertical drift velocity and density. For the longitudinal distributions between these two observables that are not good enough can be explained by including the effect of transequatorial wind to induce a hemispheric asymmetrical density distribution (shown in Figure 11) that retards the irregularity growth.

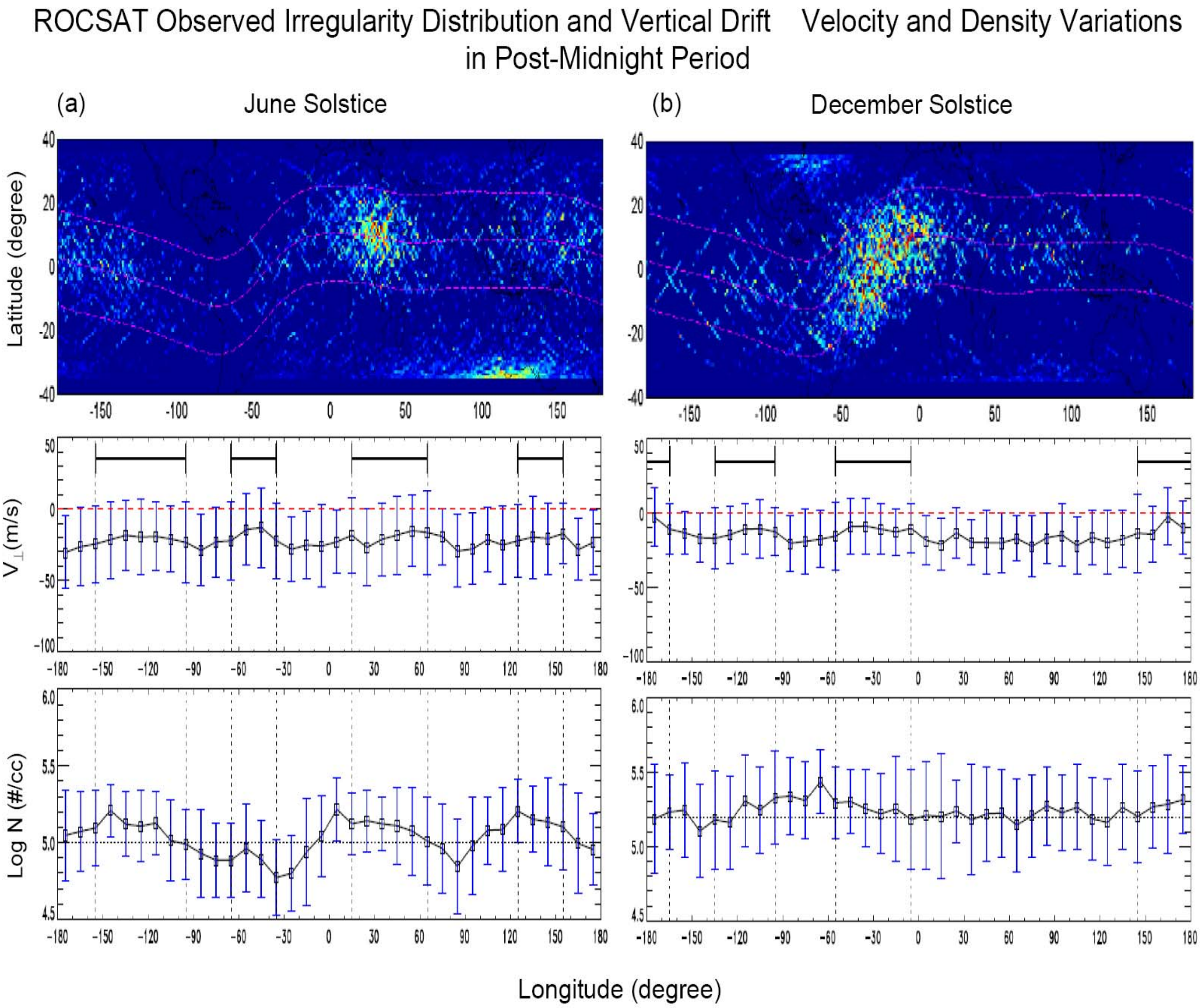

Fig. 10. Longitudinal distributions of irregularity occurrences with the averaged vertical drift velocity and density variations in the post-midnight period. (a) For June solstice and (b) for December solstice.

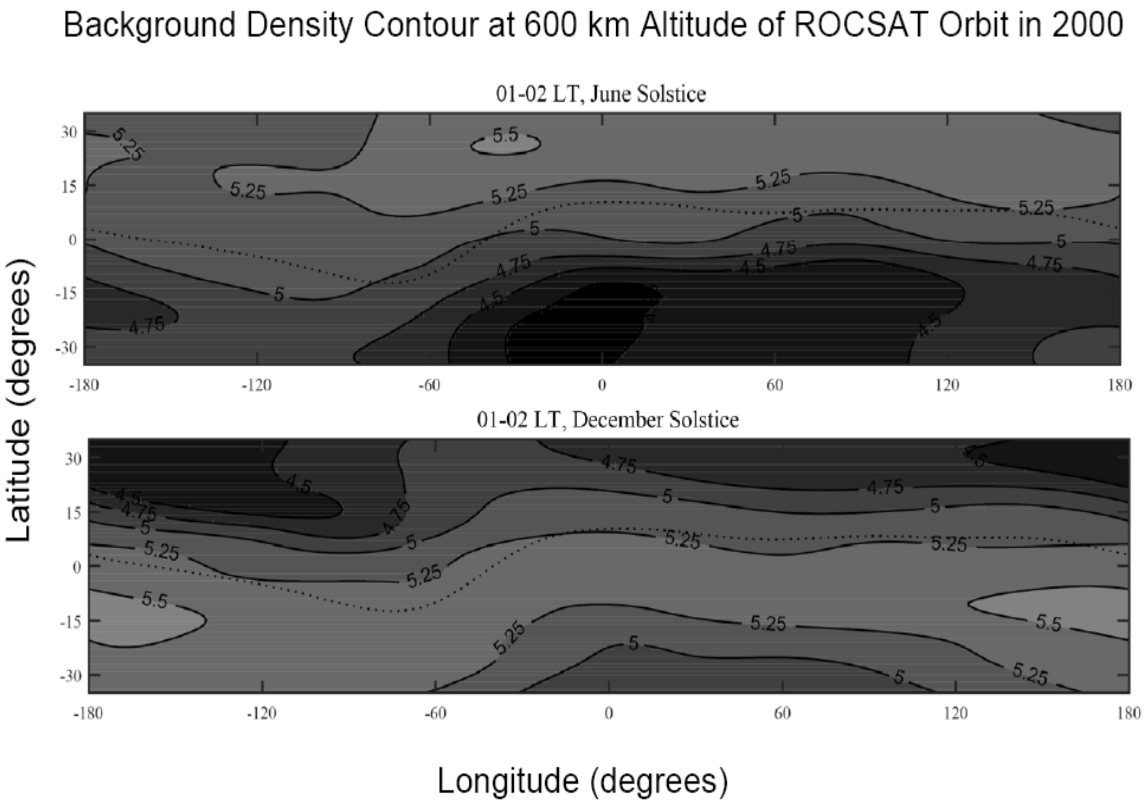

Fig. 11. Background density contours derived from the data taken by ROCSAT at 600-km altitude at 01-02 LT sector during two solstices of year 2000. The dotted line in each panel

Publications

(a) papers published in peer-reviewed journals

[1] **Journal name:** Advances in Space Research

Title: Suppression of ionospheric scintillation during St. Patrick’s Day geomagnetic super storm as observed over the anomaly crest region station Pingtund, Taiwan: A case study

Date: 24 November 2016

Authors: Chinmaya Nayak, L.-C. Tsai, S.-Y. Su, I. A. Galkin, R. G. Caton, K. M. Groves.

[2] **Journal name:** GPS Solution

Title: Global morphology of ionospheric F-layer scintillations using FS3/COSMIC GPS radio occultation data.

Date: 7 December 2016

Authors: Lung-Chih Tsai, Shin-Yi Su, Chao Han Liu

(b) papers published in peer-reviewed conference proceedings,

None

(c) paper published in non-peer-reviewed journals and conference proceedings, None

(d) conference presentations without papers

[1] Conf. name: 2014 Fall AGU Meeting
Title: On Seasonal/longitudinal Distributions of Post-Midnight Quiettime Equatorial Ionospheric Irregularities
Date: December 15-19, 2014

[2] **Conf. name:** 14th International Ionospheric Effects Symposium
Title: On Seasonal/longitudinal Distributions of Post-Midnight Quiettime Equatorial Ionospheric Irregularities
Date: December 15-19, 2014

[3] **Conf. name:** 2015 Fall AGU Meeting
Title: Reexamining the Longitudinal Distributions of Post-Sunset Quiettime Equatorial Ionospheric Irregularity Occurrences During Solstices
Date: December 8-12, 2015

[4] **Conf. name:** 2016 Fall AGU Meeting
Title: Zonal Drift Variations and Suppression of Ionospheric Scintillation During St. Patrick's Day Storm Observed by Pingtung SCINDA Station in Taiwan
Date: December 12-16, 2016

[5] **Conf. name:** 2016 Fall AGU Meeting

Title: Can Earthquakes Affect Ionospheric Scintillation? First Observations of Earthquake signatures in VHF Spaced Receiver's Data

Date: December 12-16, 2016

[6] **Conf. name:** U. S.-Taiwan Defense Armaments Cooperation and Exchange Forum

Title: Study of Equatorial Ionospheric Irregularities for the Assessment of Impacts on Communication/Navigation System

Date: 30 November, 2016

(e) manuscript submitted but not yet published

[1] **Journal name:** Advances in Space Research

Title: Post-midnight Equatorial Irregularity Distributions and Vertical Drift Velocity Variations During Solstices

Date submitted: 30 March 2017 **Authors**: S.-Y. Su, C. H. Liu, and C. K. Chao

**Article has been published since original final report was submitted.